Who owns the plant biomass? Designing a process of co-management of crop residues for cattle and soils in Sudano-Sahelian Africa

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Abstract: *Over the past 30 years, the southern part of the Sudano-Sahelian Africa, hosted a large population of farmers and Fulani herders in search of arable land and pastures. They have developed agricultural practices that maintain soil fertility through long fallow periods, and pastoral practices that allow the best exploitation of the feed distributed along the space during the time. But today, the high human pressure on resources and the global climatic change disturb this balance. The natural grazing land is cultivated by farmers in order to extend crop production; while the historical free grazing right of farmer's crop residues by herds is now challenged. Competition, tensions and conflicts have become common for the utilization of crop residues in their natural state (cattle feeding or cropping systems based on mulch), or when they are recycled in manure. The challenge is to insure simultaneously the forage supply for herds, and the preservation of soil fertility. Participatory analysis of practices (approach of local knowledge and follow-up of cropping and livestock systems), experiments and discussions with stakeholders have been carried out in the northern Cameroon (NC), south of Mali (SM) and west of Burkina Faso (WBF). The indicators of practices helped to design two innovative models of management of plant biomass. The first model explains the present and innovative process of production and of utilization of biomass according to the diversity of family farms. The second one focuses on the way the needs of stakeholders can be took into account to build the "win-win" mechanisms of management and of sharing the biomass between farmers and herders on the territory.*

Keywords: *Sudano-sahelian Africa, farming systems, livestock, crop residues*

Introduction

In sudano-sahelian Africa, recurrent drought and population growth (2 to 3% per year) resulted in an influx of farmers and Fulani's pastoralists in search of arable land and pastures, in wetter areas (700 to 1200 mm per year) in the 70s. On new land, farmers have cleared the "bush" to install plots of crop. They have developed long fallow practices to maintain soil fertility. The Fulani herders have set up their villages near ones of farmers, so as to facilitate the access of the cattle to areas rich in fodder during the rainy season (pasture on mountains and plains not infested with tse-tse) and dry season (crop residues on cultivated area, grazing lowland). But today, the disappearance of fallow, the natural mineralization of soil organic matter and the exportation of crop residues both by producers and cattle away from the plots where they have been produced, have led to declining of the soil fertility. Similarly, the disappearance of pastures, has made difficult, feeding and movement of cattle. These changes have giving rise to intense competition and conflict among actors for access to space and to water, and especially for the use of the plant biomass present (Dongmo et al., 2007; Dongmo, 2009).

A research has been carried out to test the hypothesis assuming that "a better management of biomass can lead simultaneously to the improvement of soil fertility, better supplying of forage to cattle and crop-livestock integration on the territory". Three specific objectives were pursued: i) characterize the biomass production system according to different types of family farm; ii) characterize and quantify interactions between farming and livestock systems concerning utilization and recycling of biomass; iii) building and discuss at two scales (family farm, village territory), the innovative systems of co-management of biomass by stakeholders for better crop-livestock integration and sustainable intensification of farming systems.

Methodology

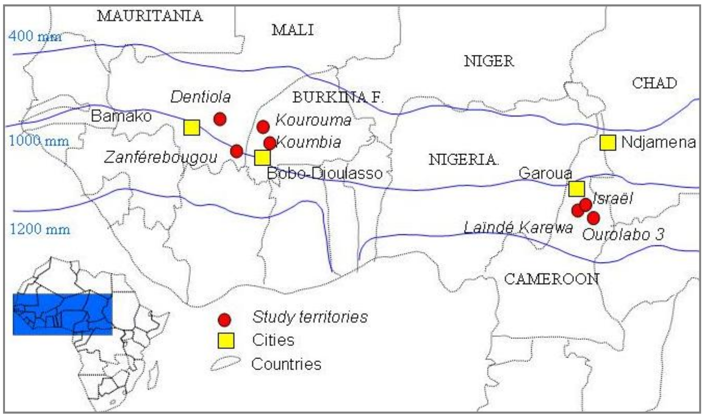
The research was conducted on a device associating 3 projects (Prasac, Duras, Cirop Teria) from 2005 to 2008 in seven agro pastoral territories (Table 1, Map 1), selected in northern Cameroon (NC), western Burkina Faso (WBF), and southern Mali (SM).

Table 1. Characteristics of agropastoral territories studied (2006).

Territories	Area (Km^2)	Pers / Km^2	ALU (%)	Nb. FF	Social groups, management of power and historical facts
Ourolabo III (NC)	14	88	76	266	Territories created between 1980 and 1985 and co-inhabited by traditional farmers (70 to 80% of the population) and the *Fulani Bororo* herders (20 to 30% of the population). Traditional authority and land rights are held by a *Fulbe* family who is the cousin of *Fulani Bororos*.
Laïnde Karewa (NC)	16	88	25	218	
Israël (NC)	-	-	-	-	
Koumbia (WBF)	97	64	35	567	Power and land rights held by indigenous *Bwaba* (35% of the population). Implantation of *Fulani* (10% of the population) in 1975 and of migrants *Mossi* (54%) in 1980.
Kourouma (WBF)	186	45	30	517	Power and land rights held by indigenous *Senoufos* ; immigration of *Fulani* in 1940 and of *Mossi* from 1980 to 2005.
Dentiola (SM)	32	84	70	167	Power and land rights held by indigenous *Bambaras* (35% of the population). Immigration of *Sarakolé, Minianka*, and *Fulani* until 1980 and then beginning of emigration; assimilation of the minority of *Fulani*.
Zanferebou-gou (SM)	43	69	28	118	Power and land rights held by indigenous *Senoufos* (first migrants). Mass departure of *Fulani* following the loss of pasture. Large adoption of agriculture by the *Fulani* minority.

Legend: Pers : Number of persons ; Nb. FF : Total number of family farms ; ALU : Agricultural land use

On each territory consisting of one village of farmers and of one or more villages of the neighbouring herders, the global diagnosis made on all family farms (FF) has been deepened by specific surveys on 220 FF selected. The follow-up of 100 FF of farmers, and 50 FF of herders, have been conducted to insure quantification and modelling flows of biomass and the practices which sustain them.



Map 1. zone of study

Results

Farming systems and biomass production

Coexistence and evolving of different types of family farms (FF)

The sudano-sahelian is characterized by 3 types of FF which are associated with different modes of production, consumption and recycling of plant biomass (Table 2). The FF belonging to farmers are more numerous. They have less than 10 cattle and they cultivate a small area. The FF of agropastoralists are those of farmers who own more than 10 cattle or those of Fulani pastoralists who have lost much of their livestock and adopted agriculture in order to diversify. They are marginal in NC (2% of the total number of FF) compared to those of WBF (13%) and SM (30%). In WBF and SM, the processes of integrating farming and rearing are more advanced with the positive influence of assimilation of Fulani's herders and of traditional farmers on each territory. Moreover their FF are larger and have more assets.

Table 2. Characteristics of family farms (2007).

	Farmers			Agropastoralists			Pastoralists		
Characteristics	SM	WBF	NC	SM	WBF	NC	SM	SBF	NC
% FF / type	68	79	85	30	13	2	2	8	13
Assets (number)	7	7	5.5	15	20	4	8	8	4
Dependents (number)	16	11.7	11.25	33	35	10	14	15	9
Coton (ha)	2	4.5	1.8	5.2	13	1.5	0.8	0.5	0
Maize (ha)	2.1	2.6	1.6	3.7	8	1.5	0.5	1.6	1.8
Sorghum+millet (ha)	2.2	1.1	0.6	4.2	2.2	0.6	0.5	0.6	0.3
Other food (ha)	1.6	0.3	3	4	0.4	3	0.5	0	0.3
Draught cattle	2	3	2	7	8	2	4	2	1
Cattle of breeding	2	2.6	3	26	33	15	17	49	44
Donkeys	0.75	0.6	0.5	2	1.3	1	0.8	0.2	0
Sheep	1.7	1.75	4	9	9	7	4	17	7
Goats	3.2	0.5	7.25	10	6	9	3	8	11

Crop rotation and crop succession

Normally, the farmer puts up rotations and crop sequences that allow better management of soil fertility and good recovery by cereals of residual fertilizer from the cotton grown the previous year. Among farmers and agro-pastoralists of WBF and SM, the cropping system is based on cereal crops and cotton which alternate on the plot from one year to another. On the contrary, in NC before 2004, groundnuts, cereals and cotton crops each occupy 1/3 of the cultivated area. They give rise to a three year rotation on the plot (cotton-cereal-groundnut). Since 2006/2007, the food crops occupy about 2/3 of cultivated area and leading to biennial rotation (cereal/groundnut) on the farmers plots. The groundnut allows the farmers to avoid fertilizers which became very expensive since the devaluation of the CFA Francs (1994) and the recent cotton crises (2004). In NC, the purchase of fertilizers outside the cotton company is more expensive. The majority of farmers have to buy in cash in the shops.

Pastoralists cultivate mainly cereals that they have adopted during their settlement. The maize and sorghum have been grown to mark their territory and to adapt to new way of life. The cereal grains that pastoralists had usually obtained from farmers in exchange for milk before the 1970s, are now the base of food supply and of cash management of their households. With the incomes of cereal and milk, farmers can avoid the sale the cattle they regard as a heritage to be transmitted to offspring. In SM and WBF, farmers grow more cotton. In NC, the adoption of cotton production by pastoralists could allow easier access to cake of cotton for livestock feeding. But the unavailability of land and non-affiliation of pastoralists to the cotton producers' organization still a major obstacle.

Soil preparation and crop establishment

The current practices of recovery of organic manure (OM) and the prospects for innovation differ from one type of FF to another and from one region to another (Table 3). Farmers without herds especially use their little quantity of OM on crops that are more demanding in fertility. This low utilization of OM is due to the small size of the herd they owns, but also and more for their poor practices concerning the management of the crop residues. On the contrary, all plots cultivated by the pastoralists receive sufficient OM through the yardage of their large herd of cattle. The goal of pastoralists is the maximization of livestock manure on their own plots cultivated or on those of their families' members. For this, they refuse even with remuneration, to park overnight on the plots of farmers as they did formerly. So, they fear to lose a part of the OM that could then limit the increasing of yields.

The tillage of plots and planting typically begin in late May, after the first rains have moistened the ground sufficiently to facilitate ploughing by the oxen. Farmers who didn't own draught cattle, have to pay 10 000 to 12 000 [1]Fcfa / ha for the ploughing of their soil. Some farmers rely on their social networks (family support, exchange of services) to till their plots. The plots not tilled are submitted to direct seeding. The decision of ploughing or of direct seeding on a given plots is taken by a farmer by combining several indicators: availability of draught cattle; regularity of rainfall early in the campaign; soil type and crop type.

Table 3. Current practices of organic manure and possible improvement in different family farms.

<table>
<tr><th></th><th>Northern Cameroon</th><th>Western Burkina Faso</th><th>Southern Mali</th></tr>
<tr><td>Farmers with 0 cattle and less than 10 small ruminants</td><td>No manure production</td><td>Composting of garbage near the house</td><td>Composting of garbage near the house</td></tr>
<tr><td>Farmers with 2 to 4 cattle or more than 10 small ruminants</td><td rowspan="2">Soil collected from stockyard of cattle without any input of plant residues</td><td rowspan="2">Composting of garbage near the house ; Soil collected from stockyard of cattle without any input of plant residues</td><td>Composting of garbage near the house ; soil from stockyard of cattle without any input of plant residues</td></tr>
<tr><td>Agropastoralists with 10 to 30 cattle</td><td rowspan="3">Soil from stockyard ; Compost pens ; cattle manure deposited through yardage with or without crop residues supply on the plots</td></tr>
<tr><td>Agropastoralists with more than 30 cattle</td><td rowspan="2">Cattle manure deposited through yardage without crop residues supply</td><td rowspan="2">Cattle manure deposited through yardage without crop residues supply</td></tr>
<tr><td>Pastoralists</td></tr>
</table>

Among farmers, the priority of ploughing the plots is given successively to maize, cotton, groundnuts and sorghum, with respectively 80%, 65%, 46% and 38% of cultivated areas. On the contrary, 100% of maize and 81% of sorghum cultivated are ploughed by pastoralists. The ploughing is more common for late planting (after June 15) because plots are already too much invaded by weeds. Groundnut is sown between late April and early June. The tillage for groundnut production is more common on very compact soils (more clay loam soil), and in fact, only after a good rainfall. The sorghum is established immediately after the groundnut between the 1 and 15th June. However, sorghum in direct-seeding (62% of the area) is sown early in comparison to the one ploughed. The cotton is then implanted between May and July, usually after ploughing. Direct-seeding shall be done very early (before 20th June) by farmers who do not have draught cattle, to avoid yield reduction. To perform direct-seeding, farmers use weed-killers such as *Gramoxone* associated to *Diuron* if there is little weed or *Roundup* associated to *Diuron* if the weedy recovery is very important. Maize is implanted after the cotton at the end of June. The weed-killers such as *Atrazine* are used alone if the soil is ploughed or associated to *Roundup* or *Gramoxone* before direct-seeding.

Crop maintenance and mineral fertilization

The groundnut is manually weeded one time (50% of plots) or two times (50% of plots) and doesn't receive fertilizers. Sorghum is mechanically weeded using draught cattle on 57% of the total area cultivated. This mechanical weeding is reinforced, or in some cases, replaced by one (73% of area) or two (25% of area) manual weeding. The earthing-up is made on 50% of sorghum cultivated while fertilizers are not common because of their expensiveness.

The weeding of maize (mechanically on 68% of area) is followed by application of 113 kg / ha of NPKSB (15 20 15 5 1) and 94 kg/ha of urea (with 46% N) on respectively 78% and 86% of cultivated acreage of farmers. The NPKSB is provided at the recommended date (30 DAS (days after sowing)) but in quantity less than the standard 200 kg / ha recommended for fields of farmers receiving no OM. The supply of urea at 45 DAS at a dose of 85 kg / ha on farmers plots is inferior to 150 kg/ha recommended (50 kg at seedling stage and 100 kg after earthing-up occurring 30 to 40 days after emergence). In general, the weeding and the earthing-up of maize plots, respectively occur 14 and 30

[1]1 euro = 655 Fcfa

days later than recommended dates. Cotton is mechanically weeded and hilled on respectively 85% and 100% of the total area cultivated. All the plots receive the NPK and urea at doses of 120 kg / ha and 43 kg / ha in 2007/2008. The application of NPK is realized the day of weeding, which occurs on 34 days after sowing (DAS) while urea is applied at 57 DAS. These practices differ of the recommendations of the research (200 kg / ha of NPK at emergence; weeding and earthing up respectively 15 and 35 days after emergence). The urea supply is inferior to the dose of 50 kg/ha recommended. Insecticides are applied 5 to 8 times over the cotton cycle. The herders provide only 38% of their cultivated area, the amount of 59 kg / ha NPKSB in average, because they have a lot of manure directly deposited on their plots by herds. This manure also acts as mineral fertilizers of crops cultivated during the year concerned.

Yields and storage level of biomass

The overall biomass produced (Table 4), concerns both the part consumable by cattle (stalks, straw, leaves) and the part not consumed but that can be mobilized for cattle litter, building of sheds, composting (stems or canes, spine of ears of cereals, hull of groundnuts).

Table 4. Average yields (T / ha) of different types of biomass (dry matter).

Biomass / crop	Groundnut	Maize	Sorghum	Cotton	Rice	Cowpea
Grains	1.7	3.0	1.4	ND	3.5	0.6
Tops	2.9	-	-	-	-	1.1
Empty shells	0.7	-	-	-	-	-
Straw	-	3.0	-	-	4.0	-
Rachis or spine	-	0.6	0.2	-	-	-
Stem (or canes)	-	-	2.1	1.1	-	-
Leaves	-	-	1.0	0.9	-	-

In NC, the plots of pastoralists are more productive than those of farmers (maize grains: 2.8 T/ha vs 3.8 T/ha; maize straw: 2.7 T/ha vs 3.8 T/ha; sorghum grain: 1.1 T/ha vs 2.4 T/ha; sorghum stem+leaves: 2.4 T/ha vs 5.3 T/ha), because they are richer in OM, in mineral elements and well maintained. The storage of crop residues is an important goal of farmers. The quantities stored depend on the overall availability of biomass in fields, and of the means (transportation, manpower) available to realize this task before the opening of the free grazing period. During the free grazing period, any herd can exploit freely the crop residues on any plots. In SM and WBF this date is well predetermined while in NC it is unknown and can be more soon or late, depending on annual decision of customary authorities.

Consumption and recycling of biomass on space by herds

The farming practices are based on the local agropastoral schedule with 5 seasons.

Beginning of the rainy season (seeto or gataaje)

The *seeto* season is a lean food period for livestock. Some herds temporarily leave the land in search of the areas better watered which are identified by peers in the south of the region. They return after the growth of grass. The fodder crisis ends and new problems arise. The herders must better monitor their livestock to prevent damage on the plots planted first. Herders who own a large size of herd divide them usually in two groups. The first group of cattle, known as “bush herd” or “transhumant herd” comes back to the zone of "short transhumance" which is situated at 50 to 75 km from the village of origin of their owner. This herd joins the second group called “herd of house” or “sedentary herd”. The two types of herds, together, produce a large quantity of faeces on the plots of their owner or of his family members. The plots which did not receive enough animal manure during the dry season benefit from additional yardage of cattle until the end of period of ploughing (mid-July).

Full rainy season (ndungu)

During the full raining season (*ndungu*), biomass is in full production on the plots. In contrary, the fodder deficit caused by the restriction of pasture and flooding of lowland and plains are main constraints of feeding of cattle (Dongmo, 2009). Only a small proportion of cattle (herds of house) are maintained near the family. They can graze only on barren hills, and on non cultivated spaces situated between the fields, on fallow land and on livestock's trails. Per day, each herd walks on about 8 to 14 km along the village during 8 to 9 hours in search of the forage. The risk of conflict is higher at this period. It is related to damage that can be caused by herd on crops. During the second half of the rainy season (july, august, september), the plots not cultivated during the year serve as stockyard during the night. This yardage of "herds of house" during the winter is not to fertilize the most degraded lands with manure, but more for change the place of rest of cattle in order to reduce parasitism.

Harvest season (yamde)

In this season (*yamde*), grazing takes place mainly along the shallows, and secondarily on fallow. But these natural spaces are less interesting in comparison to the previous period and to the plots which are newly harvested and very rich in crop residues. The herders install a temporary park for the night on the hills or away from fields awaiting harvest.

Cold dry season (dabunde)

The harvest of products and the storage of crop residues (Table 5), shall end with the opening of the "free grazing period". The herds graze directly crop residues present on the plots, regardless of owner. During this period the herder can count its livestock (bush herds) coming back from long transhumance. The point is made by owner with the herdsman. The plots of the herder and those of his family members are well enriched with cattle manure.

Table 5. Residues of crops produced and stored on FF or abandoned on the plots.

Crop	Yields (T/ha)	Part stored on FF (%)	Remaining on the parcel at the end of storage period (T/ha)	Remaining before the new campaign in May (T/ha)
Groundnut tops	2.9	2	2.8	1.0
Stem+leaves of cotton	2.0	0	2.0	1.3
Maize straw	2.9	2	2.9	1.3
cowpea haulm	1.1	30	0.8	0.6
Rice straw	3.5	24	2.6	0.6
Stem of sorghum	2.1	11	1.8	1.9
Leaves of sorghum	1.0	12	0.9	

During *dabunde* but also during *ceedu*, the free grazing of crop residues favours the transfer of organic matter from plots of farmers for those of herders, through the yardage. The total quantity of faeces restituted on soil of a given FF varies depending on the ratio "*number of cattle held / number of ha cultivated*". For instance, this ratio varies from 8 to 20 in the FF of pastoralists in NC. The herders change the sleeping area of cattle to properly enrich their plots. Considering that the faecal excretion was estimated at 1.7 kg dry matter per cattle per night (Landais and Guerin, 1992; Dongmo, 2009), a herd consisting of 50 cattle gives a quantity of 2.5 T of dry matter faeces per month to the soil during the yardage. This quantity corresponds approximately to the dose of organic fertilizer required for 0.4 ha (Berger, 1996).

The ratio "*number of hectares of food crops whose residues are consumable by cattle / number of cattle held*" varies from 0.04 to 0.07 in the FF of pastoralists. This means that only 80 to 140 kg of crop residues are available for each pastoralist cattle during the dry season. After this period of grazing, much of the crop residues constituted by share of crop residues non consumable by cattle or difficult to collect on the ground by them were abandoned in the field. This part of crop residues in the field will change very little during the hot dry season, because cattle will seek the forage on lowland areas or will leave the land.

In hot dry season (ceedu)

In hot dry season (*ceedu*) the "herds of bush" go to transhumance early in the period. They are sometimes exceptionally accompanied by some "herds of house". On the territory during this lean period, the "herds of house" are seeking the regrowth of herbaceous perennials on flood areas. In the final circuit, the forage is scarce and the herders usually cut the leaves of trees (legumes) to feed livestock. The water supply is also difficult and all cattle lose weight.

Management practices of organic matter in the family farms

Practices of the farmers

In the beginning of the rainy season (*seeto / gataaje*), farmers clean and burn the debris and plant remains found on the plot at the end of the previous agricultural campaign. They then bring manure on the soil. In the FF of farmers, the number of cattle per ha cultivated is less than 0.75. According to their current practices of manure production, this ratio leads to only 400 kg OM / ha cultivated because of the small size of herd and small quantity of litter brought. The OM obtained is consisting of solid faeces and forage refusal. It is quite different from the one obtained from cowshed or from pits of compost as described by Berger (1996).

The spray of dried animal faeces on plots is realized by 37% of FF, on about 5% of the area cultivated, at the rate of 1.1T per ha treated. Indeed, in NC for instance, there is no pit dug for OM production, and stocks of crop residues are programmed mainly to manage the period of forage scarcity. A supply of only 1 kg of straw per day per cattle provides an OM at 75% of faeces, relatively rich in minerals but poor in carbon. With 3 to 6 kg of litter per day per animal, a more balanced manure is obtained (ratio C / N equal to 15). In contrary, the poor decomposition of litter (C / N > 30 or 40) could be harmful to crops.

In WBF and SM, farmers are making a real effort of storing waste for feeding (0.51T / FF) whose refusal, once mixed with faeces and urine, is discharged into a pit of about 10 m3 where manure accomplishes its maturation. In SM, this effort made for the storage of plant residues reflects the needs of farmers for production of organic manure.

Practices of pastoralists and agro pastoralists

One important goal of herders is to achieve the organic fertilization of all plots by using the “herd of house” or by delaying the transhumance of the “bush herd”. The herds spend a number of days well-defined on plots they wish to enhance natural fertility. The wintering yardage (may, june and july) is also carried out without litter supply on the parcels considered insufficiently enriched in dry season and to be grown the same year or next year.

During the second half of the rainy season (july, august, september), the plots not cultivated during the year are used to park the cattle overnight. Like those in WBF, herders of NC do not use the litter to produce manure in the yardage. But in WBF the herd is parked on uncultivated plots situated near the house. The OM is then transported over a very short distance to fertilize the plots which will be cultivated next year. In SM, the winter parking is enhanced by a contribution from litter in the park at night during the rainy season, but also in the dry season. The production of OM in a park using large quantities of litter provided during the dry season and the early rainy season is mostly practiced by agro-pastoralists of SM. To improve the yardage, Berger (1996) proposes to apply successively in a park or in a fixed base with thorny, 4 layers of straw or crop residues that are crushed and processed at a rate of 5 kg / cow / night for use the next year. This model has not been observed in NC.

Innovating in the management of biomass and organic matter on family farms

Among farmers

In a first stage of innovation among farmers, it seems wiser to improve soil productivity in the medium term, to provide OM primarily on the most degraded plots. This would make up the level of soil organic matter above the threshold, to regenerate the soil and facilitate the exploitation of mineral fertilizers. In this case, innovation could simply be limited to the recycling in pits of the total biomass available on plot (crop residues) and possibly those available at the house (peanut hulls, residues of maize and sorghum, faeces of cattle and small ruminants) at the end of the season. This option of innovation based on crop residues available at the house (straw, faeces, crop residues), does not require biomass importation from the bush or from other FF. The farmer is thus free from additional constraints concerning the negotiation, collect or transportation of this additional biomass. With this process, the quantity of compost produced is lower (average 1T/ha grown), but still very interesting for organic matter improvement in the most degraded lands of the FF

In a second stage more ambitious of innovation in the FF of the farmers, the objective is to produce and bring to 2T OM / ha / year in all plots. The first option is by keeping the present mode of pasture. The farmers can import the straw from bush in order to increase the crop residue remaining on land after the passage of herds. They can also, if the straw bush availability fails, focus on crops with high biomass yield (sorghum). The second option is based in the fact that the "free grazing rights on crop residues" can be amended. In this case, farmers can contractualize the grazing of their crop residues with the herders. In exchange of grazing, the herds must spray their faeces on plots where they feed crops residues. It can involve a simple turning yardage to spread faeces without a straw supply on a plot of land which will be cultivated the same year. It can also involve an improved yardage based on bringing of the straw on the plot of land which welcomes the herd to obtain a real fertilizer. This improved yardage is to stabilize the herd on a park bounded in a corner of the parcel according to the technique known as yardage of winter (Berger, 1996). The mixture must complete its maturation during the year, receiving rainfall of rainy season.

The third option is based on the situation where "free grazing right" of breeders on crop residues is completely removed. In this case, the right of use of biomass is given to the owner of the parcel. He can recycle this biomass into compost pit or on cowshed.

Among herders

With a ratio of the number of cattle / ha cultivated situated between 10 and 34, the FF of breeders are over-fertilized with organic matter (5 to 15 kg / ha / year). On the other hand, they depend almost entirely of crop residues produced by farmers for feeding their livestock during the dry season. To accommodate a possible removal or modification of "free grazing right on crop residues", innovation among breeders, could aim at increasing production of biomass consumable by livestock on their own plots and if possible in the collective grazing land (Option 1). The sale or exchange of forage biomass or OM and the establishment of contracts of grazing or yardage among herders and farmers is also an option (Option 2).

During 24 hours, a cattle weighing 250 kg ejects a total of 2.5 kg of faeces (Landais and Guerin, 1992). The share of faeces returned to the soil of the park at night is estimated at 1.7 kg DM / cattle / day for a herd stayed there 16 hours a day (Dongmo, 2009) when it returns from grazing in the evening. The ratio "number of cattle available / ha grown" is between 10 and 34 on FF of herders. This ratio thus allows the spraying of 5 to 14 t of faeces / ha / year on the soil they cultivate. This dose of animal manure (AM) is well above the recommendation of agronomists that varies from 2 to 2.5 t / ha / year (Berger, 1996). As a result, farmers are in a situation of accumulation of AM. This over-quantity of AM could be given to farmers after negotiation through the nocturnal yardage on their plots.

Innovating through coordinated management of the territory and biomass

Approach of coordinated management

Diffusion of innovations must be based on territory scales, locus of competitive interactions between farmers, herders, production systems and stakeholders. Innovation processes must be accompanied by actors partnerships in relation to the challenges faced. This involvement, whose intensity varies according to the steps, starts with the mobilization of indicators and benchmarks helping to well understand the practices of different types of players (step 1). In this step the overall diagnosis and the deep diagnosis of practices are carried out through participatory research to overcome the classic approach on which farmers and herders are very often "mere contacts and informants". These participatory analyses are led individually in each production unit, and collectively in each group of stakeholders. The second step is the approximation of point of views through a consultation led by a research institute or an independent operator. It leads to the identification of development options and contractual commitments. The third step is the implementation of commitments. Its success depends on greater involvement of extension services or development projects. They must ensure the technical support (information, organization of training and exchange visits), organizational (structuring of actors around unifying themes, support for organization of work and resources on the FF) and logistics (funding / provision of seeds, fertilizers, transportation equipment).

The implementation phase is often the weakest in projects observed in savannah areas as commitments tend not to be executed, which inhibits innovation and discourages subsequently actors involved in other projects offering this type of approach. There is a need for pragmatism. The last step focuses on monitoring and evaluation of the innovation project. It is conducted by research institutes or extension services.

A conceptual model to guide action and innovation

In addition to the concerted management of shared and biomass for livestock feeding and production of manure, the "cropping system based on mulch" (CSMB) is a form of biomass use being considered for diffusion (Mbiandoun et al., 2009). Accompanying these innovations simultaneously, can be thought and implemented from a conceptual model of crop-livestock integration (Figure 1). In this region where farmers are poor, less-trained and less-informed, the implementation of projects identified (commitments and actions) needs a strong support of public power (research and extension services) on technical, strategic and logistics aspects during a period sufficient to render the system functional.

The commitments made by the farmers, are based on the total area of parcels they wish to improve fertility, through development of CSBM, or by promoting organic fertilizer which is produced from crop residues excluded of free grazing. This implies the preservation of the plots from free grazing through a ban of cattle stay on these spaces. Farmers can then use the biomass saved on their plots to produce OM or to implement the CSMB. After a deadline fixed, the rate of improvement in yields of total biomass (crop residues + food grains) can be evaluated. This indicator is then used to manage the system and adjust the commitments of producers (farmers and pastoralists) in the second round of this innovation project.

Compensation in terms of fodder units earned by breeders through this innovative system must be at least equal to the amount of crop residues lost consecutively to the limitation of free grazing rights of breeders. They can improve the forage production either collectively on their grazing land (better management and sowing of forage) or individually on their plots grown (crop associations, pure fodder crops). After a deadline, the quantity of biomass produced is measured in terms of fodder units. This indicator helps to adjust (increasing or decreasing) the area of the plots of farmers which can reasonably be removed from free grazing without compromising the future of agricultural farming systems.

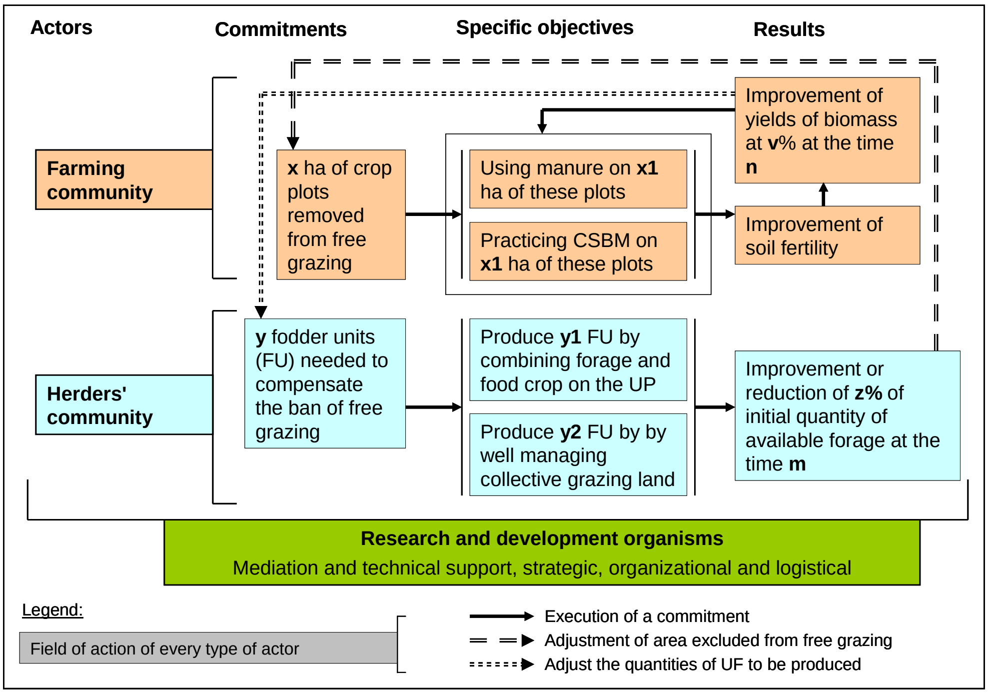


Figure 1. Conceptual model of collaborative management of the biomass on the agro-pastoral territory.

However, if forage production is not possible individually or collectively by breeders for various reasons (non-investment of herders or of research and extension services in this innovative activity), another avenue would be to induce breeders to adjust the size of their herd to a level consistent with the amount of crop residues available for livestock. In this case, herders should put in transhumance a greater part of their herd during the dry season as they already do at certain times of the year. But this option is somewhere unrealistic because in addition to food needs from rainfed crop residues, cattle also have an important function in enriching the plots of their owners in OM. Unless this option is imposed upon them, breeders can deliberately accept this option only if it is accompanied by compensation.

Conclusion

Pastoralists and agro pastoralists in the study area enrich their plots more with OM than do farmers. They get better yields but depend on crop residues of farmers to feed their large herds. The farmers whose plots are less productive are now in search of farming systems more sustainable. Innovation must also take account of the tension which is already high on crop residues and on straw bush which are needed for feed and to preserve soil fertility. The association of crops or the choice of certain crops (e.g. sorghum) can help to produce more biomass directly on the FF scale. In the sudano-sahelian, the technique of production of organic manure through composters' pits situated along the parcel helps to recycle the crop residues without any supply of animal manure and watering, but simply by exploiting rainwater annually as done by some farmers in Mali. Farmers owning cattle and transportation equipments can recycle in a pit or cowshed. Crop residues can also be concentrated on a part of the area cultivated.

At the local level, support for these innovations involves establishing new contractual rules between different actors and stakeholders. These rules must secure and guarantee both access and recovery of additional biomass produced deliberately by farmers, and secondly, the usufruct of plots fertilized by manure in view of reducing the degradation of soils and improving their productivity. The exchanges should also be encouraged between local pastoralists and farmers, because these two groups hold respectively the very large part of animal faeces and almost all crop residues of their territory. The ratio "*number of cattle owned / number of ha cultivated*" in each FF type, is a key indicator necessary to guide crop-livestock integration and sharing of biomass at the territory level.

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